OPTICAL EFFECTS OF REGOLITH PROCESSES ON S ASTEROIDS AS SIMULATED BY LASER IMPULSE ALTERATION OF ORDINARY CHONDRITE; L.V.Moroz (1), A.V.Fisenko (1), L.F.Semjonova (1), and C.M.Pieters (2). 1 - Vernadsky Institute, Russian Academy of Sciences, 117975, Kosygin St.19, Moscow, Russia. 2 - Brown University, Box 1846, Providence, RI 02912.

The spectral properties of some powdered chondrites and minerals altered by laser impulse are studied in order to estimate possible optical effects of regolith processes (micrometeoritic bombardment). Gradual reduction of overall reflectance and spectral contrast, the increase of continuum slope, the increase of spectrally derived olivine/ pyroxene ratio and Fs content of orthopyroxene with increasing alteration degree show that regolith processes could affect optical properties of surface material more heavily than has been previously appreciated.

INTRODUCTION: Ordinary chondrites (OCs) are known to account for 80% of observed meteorite falls, but so far no main belt parent bodies have been identified for these meteorites. S-asteroids resemble OCs spectrally, but are characterized by a steeper red continuum unlike that of OCs and their spectrally derived mineralogies are far outside OC range [1]. Attempts were made to explain the spectral mismatch between OCs and S asteroids by some process, which alters optical properties of uppermost regolith. However, the spectral studies of shocked (black) OCs [2], gas-rich OCs [3], melted OCs [4] and synthetic metal-rich regoliths derived from OCs [5] demonstrate that such altered OC materials darken, but do not redden.

EXPERIMENTAL PROCEDURE: To evaluate possible spectral effects of regolith processes on asteroidal surfaces the powdered specimens of Elenovka (L5), Allende (CV3), pure olivine and clinopyroxene and ol-cpx mixture (50/50) were treated by 1.06 μm laser impulse in vacuum 10^{-4} Torr (spot's focussing diameter 0.1 mm). Initial samples ("unaltered") were ground and sieved to particle size <75 μm and their spectra were measured. The specimens after treatment by laser impulse were sieved. The spectra of finer separates (<75 μm; "partly altered samples") have been recorded. More heavily altered coarser size fractions were ground to a particle size < 75 μm ("altered samples"). Among other effects, the samples after the treatment contain a lot of glass. Reflectance spectra of these samples were also obtained. Bidirectional reflectance spectra in the range of 0.3-2.7 μm at a viewing geometry $i=30^{\circ}$, $e=0^{\circ}$ were recorded with NASA RELAB instrument at Brown University. Straight line continuum removal has been performed in some cases to isolate specific absorption bands. Band centers were calculated by fitting a quadratic equation to 10 data points on either side of visually determined center. The ratios of the areas of 2 μm absorption feature (band II) to 1 μm one (band I) [6] have been calculated for Elenovka series.

RESULTS: The most obvious spectral changes are a drop in overall reflectance (darkening) and a reduction of spectral contrast with increasing alteration degree (Table 1 and Fig.1). Such optical effects are observed for shocked OCs [e.g. 2], gas-rich OCs [3], fused OCs [4]. More striking effects are:

1) A continuum slope reddens noticeably with increasing alteration degree. For example, $R_{2.5}/R_{0.56}$ ratio raises from 1.043 for unaltered Elenovka sample up to 1.49 for altered one (the value similar to that of S-type asteroid 8 Flora, Fig.1). $R_{2.5}/R_{0.56}$ range for Allende samples is 1.159-1.494. $R_{2.5}/R_{1.8}$ ratio for olivine series changes from 1.007 (unaltered) up to 1.086 (altered).

2) Alteration caused by laser impulse results in the shifts of wavelength positions of band I and band II centers (Table 1). Band I moves from 0.94 μm (unaltered) up to 1.05 μm (altered) for Elenovka series. The band I position is a function of relative abundance and composition of olivine and orthopyroxene phases. The band moves toward longer wavelength with increasing olivine abundance as well as increasing ferrous iron content [7]. The lesser shift to longer wavelength with increasing alteration degree are observed for band II (Table 1). Band II position is sensitive to Fs content of pyroxene [8]. Calibration of Adams [8] appears to overestimate Fs content of unaltered Elenovka opx (Table 1). Actual Fs content of Elenovka opx is 22 [9].

3) The 2 μm/1 μm (BI/BII) band area ratio for Elenovka series decreases as the result of alteration. BI/BII area is primarily a function of relative abundance of ol and opx phases [7]. Ol/px ratio by weight increases from 2.8 for "unaltered" Elenovka to ~ 5.4 for "altered one". Similar trend can be observed for olivine-clinopyroxene series (50/50).The data of Cloutis and Gaffey [6] allow to roughly estimate cpx abundance, using the position of tangent intercept. "Tangent intercept" (Table 1) is a position of intersection point of a horizontal straight line tangent to the peak near 0.7 μm with the long wavelength side of band I [6]. Spectrally derived cpx abundance decreases from 50% for "unaltered" sample to 0-18% for "altered" one.

IMPLICATIONS FOR S-TYPE ASTEROIDS: Shown in Fig.1 are the spectra of Elenovka series compared to the spectral reflectance curve of 8 Flora [5]. The spectral slope of "altered" Elenovka sample (curve 3) is comparable with that of 8 Flora, although the Band I and II positions and BII/BI area ratios are different [5]. Fig.2 shows the band I centers plotted relative to the BI/BII area ratios for 23 S-asteroids and Vesta compared to those of chondrites, achondrites (from [5]) and Elenovka series. The point for Elenovka OC shows a shift from "chondritic" field ("unaltered" sample) to the field of olivine rich S-asteroids ("altered" sample). Laser impulse alteration raises spectrally derived ol/px ratio up to 5.4. This value is far outside OC range (~ 0.6-3.5 [10]), but within the ol/px range for S-type asteroids (usually 1.5 - 6 [11]). The results suggest that micrometeoroid impacts simulated by

OPTICAL EFFECTS OF REGOLITH PROCESSES: Moroz L.V. et al.

laser impulse can enhance spectral similarity between S asteroids and OCs in terms of spectral slope and spectrally derived ol/px ratio. Thus, regolith processed OC-like material may be presented on the surfaces of S-type asteroids, if these surfaces contain impact glass. The data obtained in this study demonstrate that reflectance spectra of atmosphereless bodies should be interpreted with great caution, especially if impact glass formation is anticipated.

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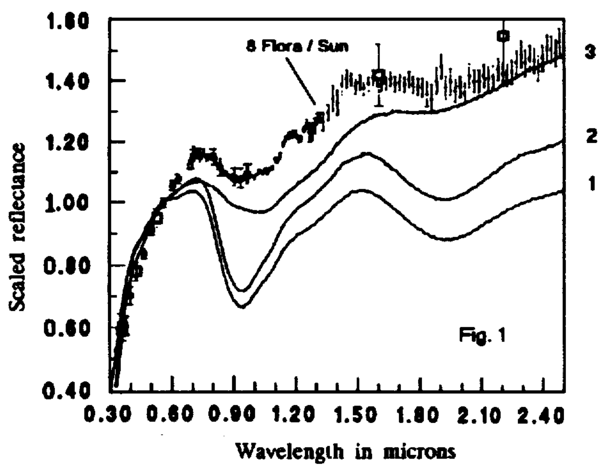
Fig.1. Normalized reflectance spectra (scaled to 1 at 0.56 μm) of S asteroid 8 Flora (from [5]) and the series of Elenovka (L5) samples (particle sizes <75 um). 1 - "unaltered" sample; 2 - "partly altered" sample; 3 - "altered" sample. Fig.2. The band I position versus BII/BI area ratio for 23 S-asteroids and Vesta (solid triangles) compared to those for chondrites ("x" symbols), achondrites (" + " symbols)(All the data are from [1]) and the series of Elenovka (L5) samples (our data). Symbols: closed square - "unaltered" and "partly altered" samples; open square - "altered" sample. The solid line is the approximate trend of ol-opx mixtures [7].



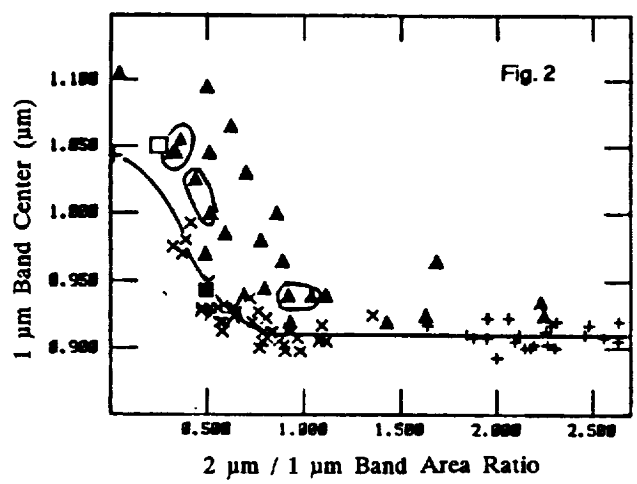


Table 1. Various spectral parameters of some materials used in this study

Sample	Band centers I	Band centers II	Band depth [12]	$R_{0.56}$	Tangent intercept	Peak at 0.7 μm	BI/BII ratio	opx (w%) / opx+ol	ol/px ratio	Fs [8]
ELENOVKA (L5) series:										
unaltered	0.940	1.934	0.363	0.31	1.48	0.71	0.501	26.1	2.8	36
partly altered	0.942	1.936	0.349	0.23	1.37	0.72	0.491	25.7	2.9	36
altered	1.051	1.963	0.160	0.16	1.22	0.75	0.250	15.6	5.4	44
OLIVINE series:										
unaltered	1.055	-	0.452	0.73	1.54	0.57				
partly altered	1.059	-	0.368	0.49	1.38	0.70				
altered	1.072	-	0.174	0.24	2.27	0.75				
OLIVINE-CLINOPYROXENE (50/50) series:										
unaltered	1.047	2.324	0.363	0.55	1.27	0.73				
partly altered	1.048	2.325	0.361	0.44	1.22	0.76				
altered	1.046	1.886	0.296	0.46	1.52	0.60				